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THE CHARM OF THE NEAR FUTURE

Sergio P. Ratti

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Via A. Bassi, 6-27100 Pavia (Italy) Telefax 0382/423241

The charm of the near future

Sergio P. Ratti
Dipartimento di Fisica Nucleare e Teorica della Universita' di Pavia Pavia U.
and
Istituto Nazionale di Fisica Nucleare - Sezione di Pavia
via A. Bassi, 6 - I27100 Pavia (PV) Italy INFN, Pavia

1. Introduction

What might be charm physics in the near future is relatively easy to imagine: pretty similar to the physics of the running experiments, but not much so. Thus it can be anything! The list of issues and problems and open questions is so large that it becomes very uncertain to envisage what will be our knowledge a decade or so from now. The accumulation of knowledge in charm physics followed in the past the increase in the number of charm events fully reconstructed. J.A. Appel[1a] in the introduction to CHARM2000 presented the plot shown in fig. 1 (completed to include data from the Cern experiments). Till the end of the eighties, the yield grew as much as about 10^5 events reconstructed by E687 in photoproduction, E791 and WA89 in hadroproduction. The next generation experiments (E831 and E781) are planned to collect in the near future some 10^6 fully reconstructed charm events. Increasing by an order of magnitude the number of reconstructed charm events, however, might not mean much if the technology and the performances of the new experimental setups will not meet new ambitious targets. Increasing by a factor of 10 the number of events but leaving the same background levels would gain only a factor $\sqrt{10}$ in the goodness of the signals. Thus background rejection is one of the challanges for the charm experiments of the near future.

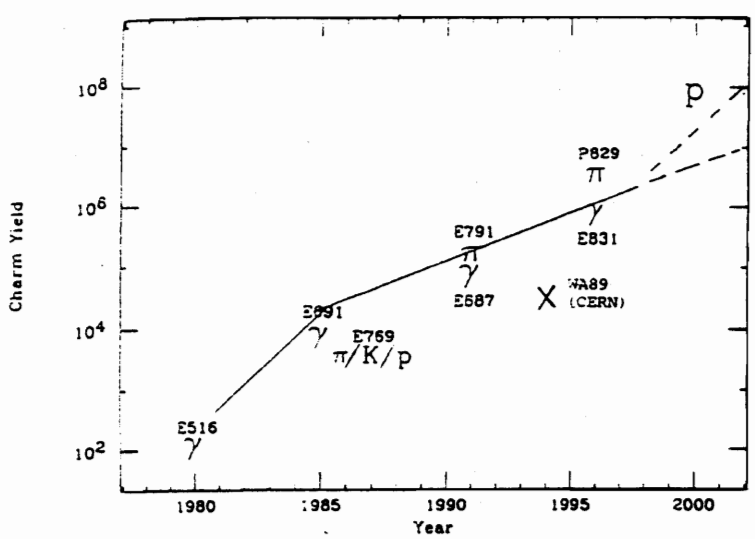

Fig. 1 Progression of the number of reconstructed charm events in fixed target experiments

The recent and present experiments, from Argus to Cleo-I-II, from E691-E791 to E687, from WA82-WA92 to WA89 (although we consider it a present experiment as it has already collected all data and the analysis is in progress) have produced (or will produce any day) a lot of very significant results on charm physics; however, the more we know, the more we need to know. The experiments of the near future are CLEO-III, E831 and E781 and their contribution to the development of charm physics will be essential to the progress of Science. LEP (see the presentation by Dominique Pallin to this Workshop[2a]), Hera and the hadron collider at Fermilab will certainly provide also additional data; however they are not "dedicated" to charm and not setup to address the most topical questions of this particular field of physics. Our knowledge of charm production by neutrinos is very scanty. No neutrino experiment has provided information at the level equivalent to that provided by hadro- and photo-production experiments. The planned experiments [NOMAD[3a]. and CHORUS[3b]] might provide a good measurement of the charm mass, however they are both definitely focussed on the issue of the ν_μ - ν_τ oscillation rather than on charm production.

What questions the future experiments are expected to answer is a long and impressive list, in spite of the fact that we are dealing with only one of the six fundamental quarks.

We need to investigate both charmed mesons and charmed baryons; for both groups of particles we need to investigate production mechanisms and decay processes; for both phenomena, the theoretical setup is not always assessed in its final form and it is far from being fully satisfactory.

In the present paper we will not enter into the details of the future programs of collider experiments and rather concentrate on the fixed target experiments such as E831 and E781. Certainly CLEO-III will take a big advantage from the insertion of a very precise vertex detector into the new apparatus, will certainly be able to contribute to almost all issues but probably not to the baryon lifetime knowledge and to the doubly charmed particles issue. A. Freyeberger has recently reviewed the excellent results on semileptonic decays at $e^- e^+$ machines[4a]; the prospect of the experimentation at future τ-charm factories has also been discussed elsewhere[4b]. The future prospect of the precise spectroscopical searches of hidden charm states has been covered by the presentation of Kamal Seth to this Workshop[2b].

2. Charm production

The theoretical knowledge of charm production is not yet fully satisfying. It is definitely a very difficult task as charm production is a laboratory to study non perturbative effects and to challenge calculations at higher order's approximation. In QCD, the lowest order processes -leading order approximation (hereafter LO)- are photon-gluon fusion for photoproduction [$O(\alpha_s\alpha_{em})$] and gluon-gluon and quark-antiquark annihiliation for hadroproduction[$O(\alpha_s^2)$]. Old lowest order LO calculations required a low mass for the charm quark (m_c=1.2 Gev/c^2) to reproduce the magnitude of the measured cross sections, a situation that was rather unconfortable. A major improvement was reached, in recent years, from the theoretical standpoint, when calculations at next to leading order (hereafter NLO) -i.e. at order $O(\alpha_s^3)$ for hadroproduction[5] and at order $O(\alpha_s^2\alpha_{em})$ for photoproduction[6]- were completed. These calculations, using a more reasonable mass for the charm quark (m_c=1.5 Gev/c^2) provide cross sections that are larger by about 30% for photoproduction and by about a factor 3 for hadroproduction. Thus, calculations including higher order terms may cure these moderate discrepancies with a more reasonable mass for the charm quark. As known[7] however, the inclusive distributions of both variables x_F and p_t^2 are not very sensitive to higher order corrections, while charm-anticharm correlations are.

Nason, Dawson and Ellis[5b] and Mangano, Nason and Ridolfi[5c], provided full parton NLO cross section calculations including gluon-gluon→quark-antiquark and quark-gluon→quark-antiquark processes. Several available models based on LO perturbative QCD provide calculations to order $O(\alpha_s^2)$; some models[5b], provide calculations of hadroproduction inclusive distributions at NLO which are in good agreement within one another. Calculations of fully exclusive distributions of heavy quark hadroproduction[5c] have been also performed and applied to fixed target experimental configurations of current interest. Distributions of heavy quark photoproduction have also been computed[6b]; the same technique of ref. 5c have been applied to

photoproduction[6d] to obtain fully exclusive distributions. It is worth mentioning that photoproduction and hadroproduction are different essentially only in the conversion of the initial state into the first step. The conversion of the initial photon into a quark-antiquark pair is *a fortiori* the very first step of photoproduction, limited by all initial kinematical constraints. Starting from the first produced quark (antiquark) onwards, the (quantumchromo) dynamical mechanisms are basically the same for both photo- and hadroproduction processes. The fragmentation functions are usually evaluated on the basis of Montecarlo simulations of the three basic different models: string fragmentation, cluster fragmentation and/or independent fragmentation[8]. Well known are the programs ISAJET[8a], PYTHIA[8b], EUROJET[8c], FRITIOF [8d], HERWIG [8e] used to model the finally observable kinematical distributions. In any of the models, the free parameters to adjust are essentially four: 1- the quark-gluon structure function of the nucleon g(x) for photoproduction and/or the partition function $q(x_1,x_2)$ for hadroproduction, where $x=s^*/s$ is the share s^* of the energy s carried by a given quark participating into the elementary interaction; 2- the scale factor μ related to the running coupling constant α_s and to Λ_{QCD} by: $\alpha_s \approx 1/[b \ln(\mu^2/\Lambda^2_{QCD})]$, where b is a constant and μ may vary within the range $0.5m_c \leq \mu \leq 2.0\ m_c$; 3- m_c the charm quark mass; 4- the details of the fragmentation model. As an example, LUND PYTHIA contains LO calculations plus approximate NLO order corrections (the SHOWER package) plus a classical string fragmentation model; HERWIG contains LO calculations plus approximate NLO corrections (the SHOWER package) plus a cluster fragmentation model.

NLO corrections -about 30%- are approximately sufficient to reproduce the σ_{tot} vs. energy and inclusive production cross sections, however NLO corrections are basically unable to reproduce the color dragging leading effect studied in details by NA82[9a] and E769[9b].

The asymmetry parameter $A=(N_{leading} - N_{non\text{-}leading})/(N_{leading} + N_{non\text{-}leading})$, plotted in fig. 2 for the two experiments, as a function of x_F and compared to the straight NLO calculation (dashed line) and to the prediction when the Lund string fragmentation model is implemented into PYTHIA (dash-dotted line), shows a definite disagreement.

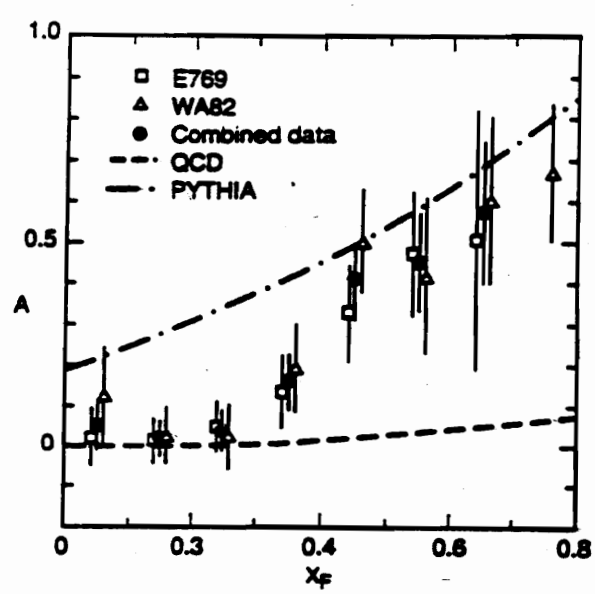

fig.2 Leading charm asymmetry A vs. x_F observed in h-h collisions.

The experimental data lie between the two curves; the improved calculation seems to be less inconsistent with the overall trend of the data, which however show a rising between $0.3 < x_F < 0.4$ sharper than accounted for by the improved model. E769 found similar results for D^+ and D^{*+} events and observe that the asymmetry is independent of the transverse momentum.

Ramona Vogt[2c] has shown in her talk that this effect can be cured by introducing intrinsic charm coalescence into particular models.

An additional field where QCD calculations provide rather poor predictions is charm anticharm correlations. Photoproduction[10a-c] as well as hadroproduction[9b,11] experiments have selected quite a few fully reconstructed or doubly tagged charm-anticharm events (the tagging being the soft pion from $D^{*+} \rightarrow \pi^+ D^o$ that allows to discriminate charm from anticharm using also the D^o samples) and compared to theoretical models distributions such as the charm-anticharm rapidity gap Δy_{cc}, the relative trasverse momentum p_t^{cc} carried by the charm pair, the energy share $z=(E_{charm}+E_{anticharm})/E_{beam}$, the mass M_{cc} and the acoplanarity angle $\Delta\phi$ (where ϕ is the azymuthal angle between the two charmed particles in the plane perpendicular to the incoming beam axis), as a tool to challenge the QCD predictions at a higher level. The Δy_{cc} and z distributions show reasonable agreement with NLO QCD calculations for both photo- and hadro-production; both photo- and hadroproduction p_t^{cc}'s show broader distributions than calculated by NLO QCD, requesting the introduction of some extra p_t kick to the gluon[5b,6d]. The introduction of the p_t kick is essential to recover the agreement between data and NLO calculation. The variable most sensitive to the production mechanisms of a charm-anticharm pair is the acoplanarity angle $\Delta\phi$ which is affected by the QCD details.

TABLE I: Charm production asymmetry compared to LUND-Pythia predictions

Decay mode	Exp. values[9d] α (average)	Model prediction [9d] α (theor.)
$D^+ \rightarrow k^-\pi^+\pi^+$	-3.8 ± 0.9	-12.7 ± 0.5
$D^{*+} \rightarrow D^o\ \pi^+ \rightarrow (k^-\pi^+)\pi^+$	-6.4 ± 1.5	-0.8 ± 0.9
$D^{*+} \rightarrow D^o\ \pi^+ \rightarrow (k^-\pi^+\pi^+\pi^-)\pi^+$	4.0 ± 1.7	-11.5 ± 1.0
$D^o \rightarrow k^-\pi^+$ (no tag)	-2.0 ± 1.5	-3.6 ± 0.6
$D^o \rightarrow k^-\pi^+\pi^+\pi^-$ (no tag)	-1.9 ± 1.5	-6.9 ± 0.7
$D^+_s \rightarrow k^-k^+\pi^+$	$+2.5 \pm 5.2$	$+4.3 \pm 0.1$
$\Lambda^+_c \rightarrow pk^-\pi^+$	$+3.5 \pm 7.6$	$+17.4 \pm 1.6$

Even worse is the prediction of the asymmetry observed in charm-anticharm photoproduction by E687[10d] and E691[10e]. In particular E687, starting from a sample of about 55,000 fully reconstructed charm events (D's, D*'s, D_s's and Λ^+_c's)[10d] has selected about 12,000 charm-anticharm mesons D's or D*'s, 725 D_s's and some 830 Λ^+_c's and measured the asymmetry parameter $\alpha=(N_{charm}-N_{anticharm})/(N_{charm}+N_{anticharm})$ and the ratio $R=N_{anticharm}/N_{charm}$. The high statistics new measurements of R are in good agreement with the measurements performed by E691 and consistent with the measurements of NA14[10a]. Table I compares to the Lund-Pythia predictions the average values of the asymmetry for different decay channels. The average values of α (Table I), are barely consistent with the NLO QCD predictions. Definitely in disagreement[7] are the values for D_s's and Λ^+_c's. Fig.s 3, show the asymmetry parameter measured for different bins of p_t^2- (fig. 3a), of incoming beam energy -centered around values from 40 GeV to 280 GeV- fig. 3b) and of x_F (fig. 3c), for D^+ (upper part) and $D^{*+} \rightarrow D^o\pi^+ \rightarrow (K^-3\pi)\pi^+$ (lower part). The asymmetries are much smaller than those predicted by NLO QCD calculations. The dependence on p_t^2 in fig. 3a is barely detectable experimentally, while it is relevant, for $p_t^2>1.0$ (Gev/c)^2, for the theoretical predictions. The QCD model would predict, in fig. 3b, important asymmetries at low energies which are not observed. The energy dependence, also possibly existing, is not so strong as predicted. Finally, in fig. 3c, for $x_F > 0.6$ the predicted asymmetry in favour of anticharm is at least about a factor three larger than the measured one.

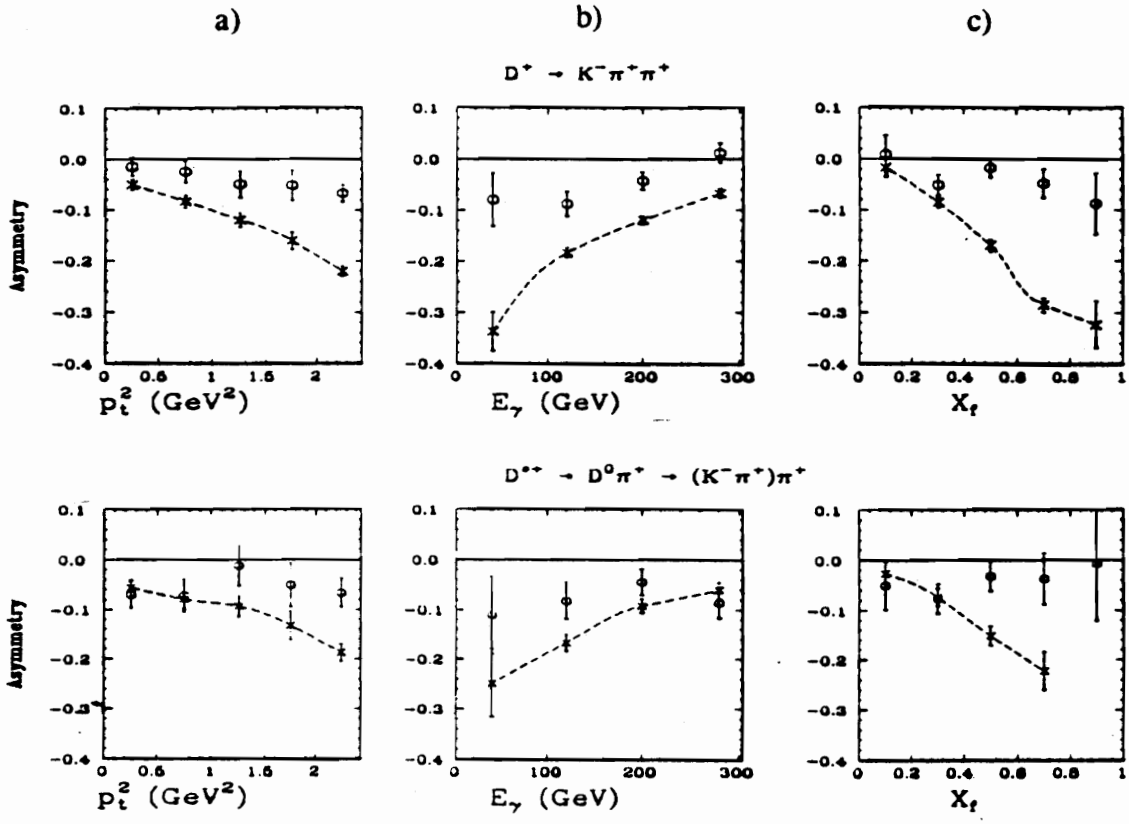

fig. 3 cc aymmetry for D^+ (upper figure) and D^{*+} (lower figure) in charm-anticharm photoproduction; x are Lund Pythia predictions. a) α vs. p_t^2; b) α vs. beam energy; c) α vs x_F.

The experimental data are well consistent with very small asymmetry, while QCD calculations predict substantial asymmetry implying -at least for the case of the Λ^+_c baryons- more associated production than observed. This is an issue that requests a confirmation; the experiments of the near future will provide by far more accurate measurements able to even further challange the theoretical calculations.

It appears, in general that the theoretical description of charm production, when successful, always requires some ad hoc assumption. The crucial point, in our opinion, could be the inclusion into the fragmentation function calculation of the complete multiplicative cascade process that implies non-gaussian statistics and possible severe fluctuations into the fragmentation process[12].

3. Charm meson decays

Contrary to the case of charm production, the basic theory of charm decays is very well established being the Standard Model for Electroweak Interactions. What is not known and has to be indicated by experiments is the relative contributions of the decay diagrams compared to the exchange diagrams, the effect of colour suppression etc. Here the difficulty resides into the hadronic part of the decay -when present- i.e., again, the non perturbative QCD contribution to the processes. In addition to this, it is difficult to evaluate the effects of final state interactions, spin effects, multibody decay modes, not to mention the prediction of the absolute branching fractions of the most aboundant hadronic decay modes.

From the experimental point of view, most of what we learnt, so far, comes from the study of charmed mesons rather than from charmed baryons. By all means, we have to hope that it will not be so for the next generation experiments, although the relative aboundance of data will always favour the meson sector.

3.1 Leptonic decays

The continuous investigation of charm semileptonic decays provides a large amount of information on the form factors $f_+(q^2)$, $A_1(0)$,,$V_1(0)$, $V_2(0)$ -which have been shown to be usefull to predict beauty form factors[1c,d]- and information on the Cabibbo-Kobayashi-Maskava matrix elements. They are easier to interpret theoretically than hadronic decays. What is lacking and will be probably provided by the next generation experiments is a measurement of the W in D^o, D^+ ans D^+_s decays, as well as interference effects such as those between the two low lying K* resonant states. Fully leptonic decays such as D^+, $D^+_s \to \mu^+\nu$ or $\tau^+\nu$, estimated to be of the order 10^{-4} will allow the evaluation of the decay constants f_D and f_{Ds} which are estimated to span large energy bands: ($f_D \approx 200\pm30$ MeV; $f_{Ds} \approx 200 \pm 30$ MeV and $f_{Ds}/f_D \approx 1.15 - 1.2$). It will also be of interest to further study the q^2 dependence of charm semileptonic decays; the process $D \to \pi l\nu$ will allow one to probe much closer the possible K* pole in $f^+(q^2)$. By all means, instrumental biases and backgrounds are likely to be serious sources of systematic errors. Particle identification will play an important role as a $D^+ \to K^{*o}\mu\nu$ may look like the Cabibbo suppressed decay $D^+ \to \rho^o\mu^+\nu$ due to the misidentification of the kaon.

In addition to this, the inclusive branching ratio ($D_s \to lX$) has not been measured yet and, more generally, the overall database of the semileptonic and fully leptonic decays is highly unsatisfactory. The lepton spectra in inclusive semileptonic decays, analyzed separately for D^o, D^+ ans D^+_s mesons, will provide direct information on the weight of the weak annihilation process compared to other hadronization effects.

3.2 Rare decays

Rare radiative decays, such as $D \to \gamma K^*$, $D \to \gamma\rho/\omega$, $D_s \to \gamma\phi$, $\gamma\rho/\omega$, *per se*, are not of particular theoretical interest, as they can proceed via weak annihilation coupled to photon emission by the initial light quark, but need anyhow experimental measurements[1c]. CLEO III, with the excellent gamma detector will play an important role here.

In the Standard Model, CP violation and flavour changing neutral currents (FCNC) are expected to be very small in charm decay, while lepton family number violation (LFNV) as well as lepton number violation (LNV) are strictly forbidden. On the contrary, these effect show a very clear phenomenological signature that makes charm decay one of the best place were to look for searches on new physics beyond the Standard Model. The charm meson sector has already a relatively aboundant set of data for this kind of investigation; however, experimentally, no much more than upper limits are known so far on rare decays. J. Hewett discussed this particular issue in a separate presentation[2d], M. Purohit has covered the D^0-D^0-bar mixing issue[2e] P.D. Sheldon[1b] has collected all existing data on rare decays in a table of the Charm2000 Workshop (that is recopied here as Table II). The method used to set these upper limits is normally to try and measure a branching ratio relative to a *golden* decay mode with the same multiplicity to minimize systematic errors.

FCNC decays have the best upper limits estimated to order 10^{-4} (only the dimuon -plus eventually a pion- channels are known at a 10^{-5} level); LFNV effects are known at 10^{-3} levels (apart from the $D^o \to \mu^-e^+$ or $D^o \to \mu^+e^-$, LFNV decays estimated by the Argus collaboration[13] at 10^{-4}), while LNV upper limits are at best set to 10^{-4}. In a future perspective -and to stress the link to what can be expected from the charm experiments of the near future- we discuss the problems connected to the detection of one of these very rare channels, for instance, $D^+ \to \pi^+\mu^+\mu^-$ that is a FCNC process (or $D^+ \to \pi^-\mu^+\mu^+$ that is a LNV decay). The problems here are the rejection of fake leptons, the vertex and the mass resolutions and, finally, the combinatoric background rejection. The three issues are interlinked. Random combinatoric background rejection is obviously crucial, thus the vertex geometrical resolution is crucial. Setting an upper limit implies an error that goes as $\sqrt{N}$ if N is the background. If the fake lepton rejection is of order 10^{-2} (10^{-4} or 2 muons) and the BR for the Cabibbo suppressed decay $D^+ \to \pi^+\pi^+\pi^-$ is about 10^{-3} the

background events would set to a level 10^{-7}. Gaining a factor 10 in the rejection of fake muons would allow to set the background level to 10^{-9}. At this point the mass resolution comes into play as the fake $M(\pi^+\mu^+\mu^-)$ would be only slightly distorted by the wrong mass assignment (I shall go back to this point later).

Table II: 90% CL Upper Limits on FCNC, LFNV and LNV Charm Decays Modes in units $\times 10^{-5}$.

Type	Mode	E653	E687	E771	E789	E791	PDG (expt.)
FCNC	$D^0 \to e^+e^-$						13 MK3
	$D^0 \to \mu^+\mu^-$		2.7	1.2	3.1		1.1 E615
	$D^0 \to \rho^0 e^+e^-$						45 CLEO
	$D^0 \to \rho^0\mu^+\mu^-$	24					81 CLEO
	$D^0 \to \pi^0\mu^+\mu^-$	17					
	$D^0 \to \overline{K}^0 e^+e^-$						170 MK3
	$D^0 \to \overline{K}^0\mu^+\mu^-$	25					250 MK2
	$D^+ \to \pi^+e^+e^-$						290 MK2
	$D^+ \to \pi^+\mu^+\mu^-$	22	9.7			1.3	290 CLEO
	$D^+ \to K^+e^+e^-$						480 MK2
	$D^+ \to K^+\mu^+\mu^-$	33	8.5				920 MK2
	$D^+ \to \rho^+\mu^+\mu^-$	58					
	$D_s^+ \to K^+\mu^+\mu^-$	60					
	$\Lambda_c^+ \to p\mu^+\mu^-$	33					
LFNV	$D^0 \to \mu^\pm e^\mp$						10 ARGUS
	$D^+ \to \pi^+\mu^+e^-$						330 MK2
	$D^+ \to \pi^+e^+\mu^-$						330 MK2
	$D^+ \to \pi^+\mu^\pm e^\mp$						330 CLEO
	$D^+ \to K^+\mu^+e^-$						340 MK2
	$D^+ \to K^+e^+\mu^-$						340 MK2
LNV	$D^+ \to \pi^-e^+e^+$						480 MK2
	$D^+ \to \pi^-\mu^+e^+$						370 MK2
	$D^+ \to \pi^-\mu^+\mu^+$	20	17				680 MK2
	$D^+ \to K^-e^+e^+$						910 MK2
	$D^+ \to K^-\mu^+e^+$						400 MK2
	$D^+ \to K^-\mu^+\mu^+$	33	20				430 MK2
	$D^+ \to \rho^-\mu^+\mu^+$	60					
	$D_s^+ \to K^-\mu^+\mu^+$	60					
	$\Lambda_c^+ \to \Sigma^-\mu^+\mu^+$	72					

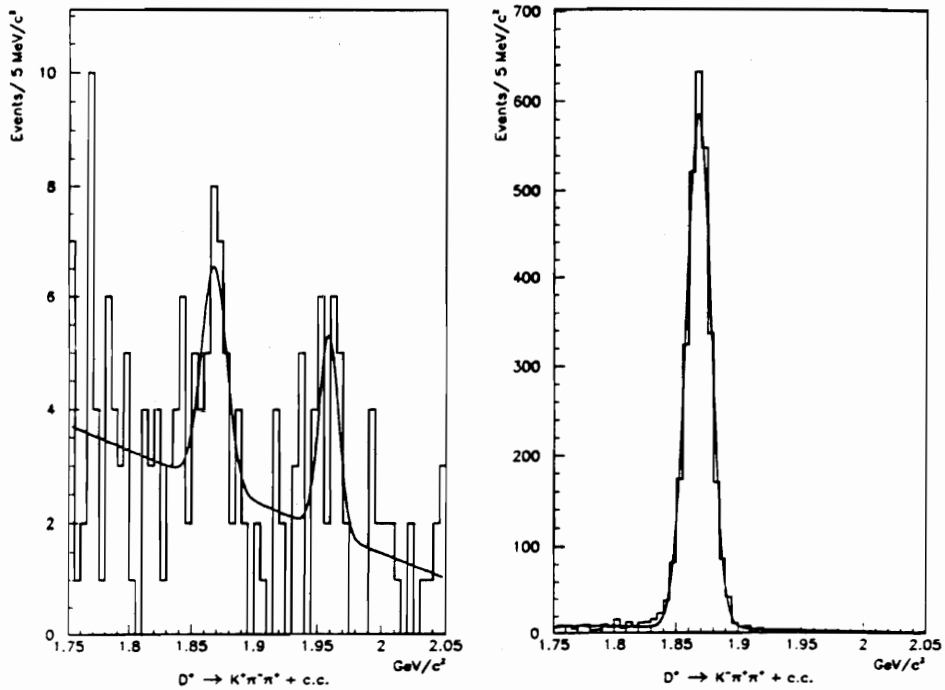

Fig. 4 a) Doubly Cabibbo suppressed channel $D^+ \to k^+\pi^+\pi^-$ (decay vertices outside the target); b) reference decay mode $D^+ \to k^-\pi^+\pi^+$ (E687 data).

Hints of doubly Cabibbo suppressed channels are observed in present experiments. In a preliminary report, E687 observed[13] a three standard deviation signal of 20.9 ± 6.6 events for the $D^+ \to k^+\pi^+\pi^-$ decay (see fig. 4a,b) at the mass m= 1868 with a width of ≈ 10 MeV/c². One might expect $\Gamma(D^+ \to k^+\pi^+\pi^-)/\Gamma(D^+ \to k^-\pi^+\pi^+) \approx \tan^4\theta_c \approx .003$, where θ_c is the Cabibbo angle; E687 estimated a relative branching ratio $\Gamma(D^+ \to k^+\pi^+\pi^-)/\Gamma(D^+ \to k^-\pi^+\pi^+)=(7.2\pm2.3\pm1.7)\ 10^{-3}$ and an upper limit .0108 at 90% confidence level. It is interesting to underline that, in order to minimize background, for the selection of the events the request was set that the decay be separated from the downstream end of the target by a factor 1.5 l_v/σ; l_v being the distance of the decay vertex from the end of the target and σ its error.

Another example of this additional cut is the evidence for the $D^+, D^+_s \to (5\pi)^+$ decay[14], which is Cabibbo suppressed for the D^+ and Cabibbo allowed for the D^+_s, shown in fig.s 5. In fig. 5a, where all selected events -according to standard selection cuts- are included, the signal/backgrond ratio is S/N=0.33 for the D^+ case and S/N=0.26 for the D^+_s case; in fig. 5b, the additional requirement that the decay vertex be outside the target moves the ratios up to S/N=4.7 for the D^+ and S/N=4.1 for the D^+_s case. This point is a crucial demand for the experiments of the near future. For the future charm experiments it will not be enough to:

- improve the number of charm-producing interactions collected;
- get better beams, better data acquisition systems;
- increase the multiwire proportional chamber's tracking resolution;
- improve the muon/pion/kaon/proton identification;
- design a better trigger.

What is also needed is:

a- a segmentation of the target as it will improve tremendously both the signal to noise ratios and the mass resolution;

b- improve the detection of neutral particle either with an electromagnetic or hadronic calorimeter (for the illustration of this point see Sect. 5).

For the illustration of the mass resolution point we will again consider the data from E687; i.e. the D^*-D^0 mass difference. Fig. 6 shows the variation of the width of the D^*-D^0 mass difference with the position of the decay vertex for the present E687 experiment; getting away from the target, the mass difference incertainty can become as low as approximately 75 KeV, a quite remarkable result.

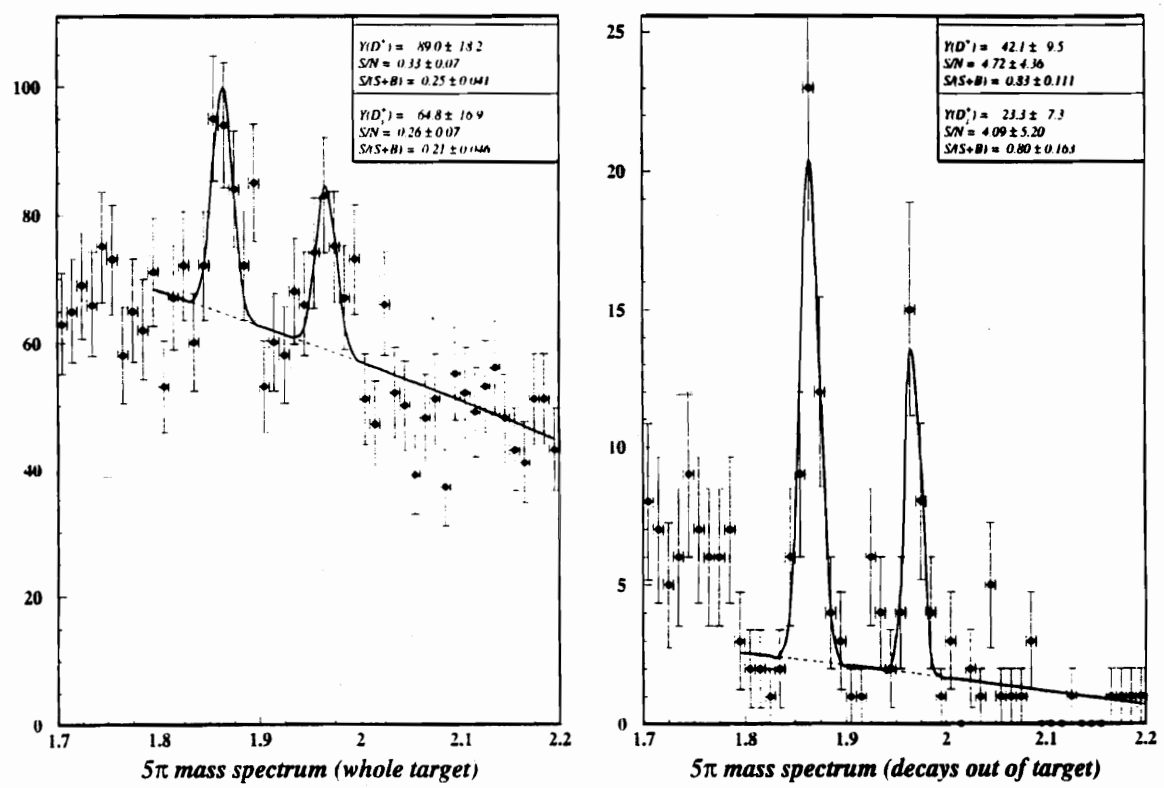

Fig. 5 M(5)$^+$ distribution for: a) all events; b) events decaying outside the target (E687 data).

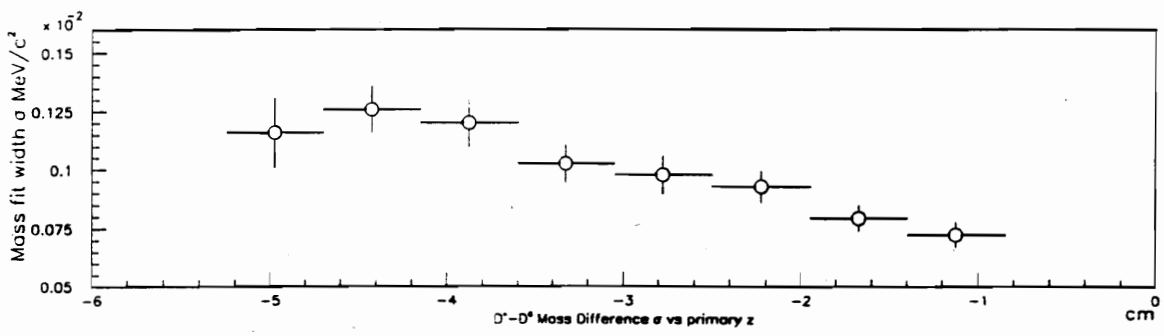

Fig. 6 Resolution for the mass difference (D^{*+}-D^0) vs longitudinal position of the decay vertex.

This advantage is unvaluable (see M. Purhoit[2e] contribution to this Workshop) in selecting the correct slow tagging pion for the CP violating candidates. This same advantage adds also up with the improvement of the S/N ratio.

A comparison of the E687 data to the Montecarlo prediction for decays outside the target for $D^0 \rightarrow k^-\pi^+$, for $D^0 \rightarrow k^-\pi^+\pi^+\pi^-$ and for $D^+ \rightarrow k^-\pi^+\pi^+$, sets ratios: 11% $k\pi$, 25% $k3\pi$, 37% $k2\pi$ decaying outside the target in the present experiment. Fig.s 7, show how, for the $k\pi$ decay of the D^0, the S/N ratio improves to 4.97 (fig. 7a) from 1.48 (fig. 7b) when all cuts remain the same but the decay vertex is required to be outside the target.

E831 studied several possible target configurations from this particular standpoint. As an example, should the collaboration adopt a diamond target of 3 slices, each 2.5 mm thick, 77% of the D^0's, 85% of the D^+'s and 57% of the Λ^+_c's would decay ouside the target if a 350 GeV average gamma energy were used for the beam.

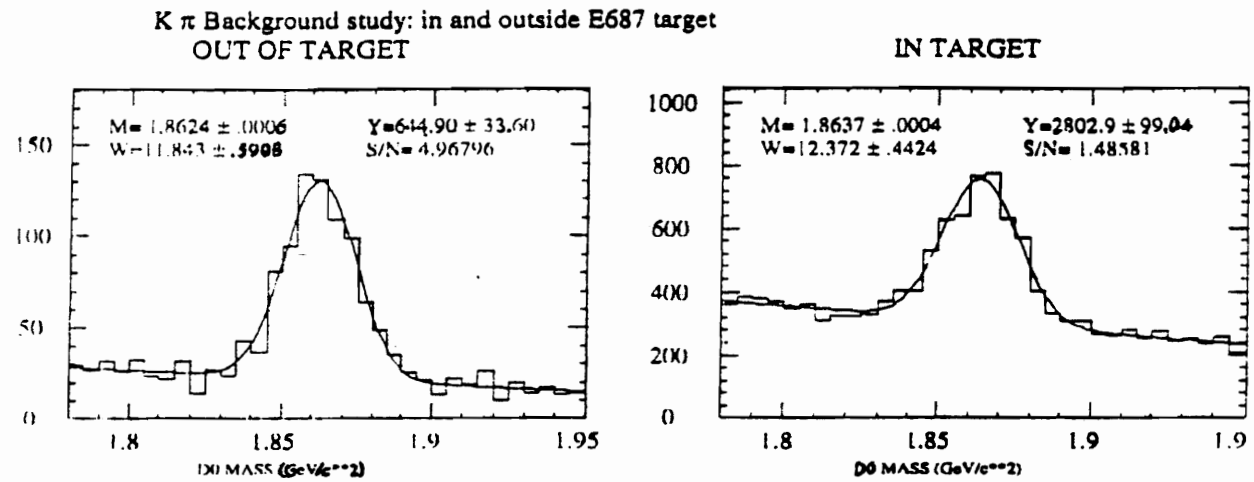

Fig. 7 M(kπ) mass distributions: a) E687 events decaying ouside the target; b) events decaying inside the target.

4. Charmed baryons

As already mentioned at the beginning, most of what we learnt on charm physics comes from the study of charmed mesons, since they are much more aboundantly produced than charmed baryons. However, the approval of an experiment such as E781 which will use a Σ^- high energy beam, might change the situation, although the number of charmed mesons produced will always prevail over the number of produced charmed baryons. There isn't much hope to improve significantly the present prospect of obtaining absolute branching fractions apart from the chance to apply already existing methods to a larger amount of data. Evidence has been so far provided for the existence of the $1/2^+$ low lying SU(4) charmed multiplet and several excited states of the Λ^+_c, however even several states of the $1/2^+$ and $3/2^+$ SU(4) supermultiplets are missing and all the spectroscopy of the charm-cascade particles has to be studied. The same applies to the sector of the semileptonic decays. For instance, the inclusive semileptonic partial widths for D^0 and D^+ are measured to be the same; it would be obviously very relevant to understand whether or not the same occurs for the charmed baryons. Due to the large backgrounds, this investigation appears to be particularly difficult; nonetheless the use of a proper "tag" might help enhancing the a given signal. It is also of interest to verify whether the exclusive one-hadron lepton neutrino channel saturates as verified in the meson sector. The aboundant statisics presumably available in the next generation experiments, together with a better signal/noise ratios might allow to study polarization effects as charmed baryons could be produced polarized[16].

4.1 Lifetimes

A systematic study of the lifetimes for the waekly decaying charmed baryons can provide information on the different roles played by spectator decay, W-exchange and all interference effects. Adding together the 7 lifetimes that can be measured experimentally (3 for the mesons and 4 for the single-charm baryons) allows one to challange the theoretical estimates for different lifetime ratios or, at least, the jerarchy of the relative values. Such study is necessarily complementary to what can be learned from charm meson lifetimes. At present, the knowledge of the charmed baryon lifetime is not yet satisfactory; to date, the lifetimes of the four single charm baryons are known to a certain extent.

Table III collects the values of all lifetimes as quoted in the Data Particle Book[17] (all most precise measurements come from E687[18]). If we assume, for the sake of the argument, that a lifetime is measured when the statistical error is less then 10%, we may state that the lifetimes of the 3 mesons and the of the baryon are indeed measured, while the lifetimes of the strange-charm cascade particles are only estimated. Recently, E687 has also estimated[18], using about 50 events, the lifetime of the double-strange-charmed baryon Ω^+_c giving $\tau = (96^{+30}_{-19} \pm 23)$ fs.

TABEL III: Summary of the charmed particle lifetimes

particle	lifetime (fs)
D^+	1057 ± 15
D^o	414 ± 4
D^+_s	467 ± 17
Λ^+_c	202 ± 12
Ξ^+_c	$350\ ^{+70}_{-50}$
Ξ^o_c	$98\ ^{+23}_{-15}$
Ω^+_c	$96\ ^{\pm 30}_{-19} \pm 23$ new

E687 measured $\tau(D^o)/\tau(D^+_s) = 1.15 \pm 0.05$. The difference between the lifetimes of D^0 and D^+_s provides information on the different contributions of the W-exchange and weak annihilation to the respective decay widths (and here $\tau(D^+_s)$ can be improved). In the baryon sector, the theoretical analysis is more complex[20]. B.Blok and M.Shifman[20b] have rivisited the subject: depending upon two different thoretical assumpions, the Ω^+_c lifetime is either close to the longest or close to the shortest of the strange-charm baryons. There is no way that the Ω^+_c lifetime be close to that of the Ξ^+_c state.

However, it appears that only WA89 might provide better lifetime estimates for the single charmed baryons in the very near future (maybe not yet with errors below 10%). E831 and E781 will certainly be able to provide good measurements.

4.2 Doubly charmed baryons

An issue addressed by the next generation experiments, depending upon the geometrical accuracy of their vertex detectors might be the discovery of baryons containing two charm and one light quark, where a rich spectrum is expected[1e,21] due to the excitations of the relative motion of the two heavy quarks in the lowest Born potential, or to the excitations of the light quark or to both. In any case the ground state of any flavour combination can only decay weakly either by the decay of one of the heavy quarks or, when possible, by a W-exchange between the constituents. A large variety of final states is expected: Cabibbo allowed, Cabibbo suppressed or doubly Cabibbo suppressed. J.M. Richard made some calculations based on flavour independen-

ce and made predictions on their possible masses, either the lowest state M_o with spin-parity $J^P=(1/2)^+$ or a spin averaged mass M_1.

The values, collected in Table IV are well reachable experimentally and the outer weak decay of a c-quark would lead to the well identifiable channels as those sketched in fig. 8. for the decays $\Xi_{cc}^{o,+} \rightarrow \Lambda/\Sigma D$ $\rightarrow \Xi_{cc}\pi$.

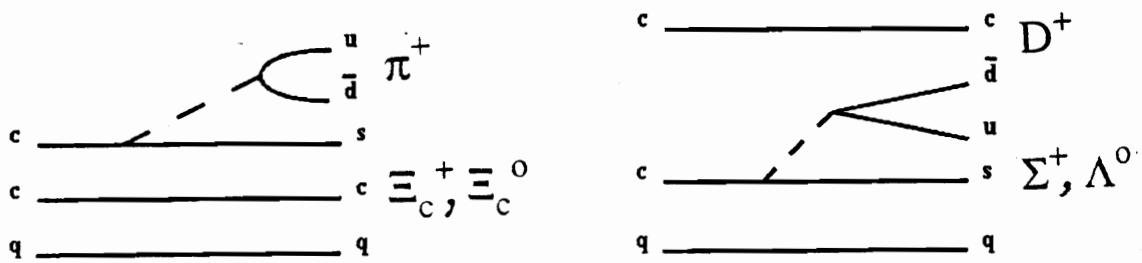

Fig. 8 Naive quark diagrams for the easiest decays of doubly charmed cascade particles

There are no estimates for the possible production cross section of such states (see Sect. 2), however, by all means, it will be not easy to separate geometrically at least three very close vertices. Nonetheless the challenge is exciting and a favourable portion of good luck might make these states at least detected.

TABLE IV: Theoretical estimates for the masses of doubly charmed baryons

State	(ccu) or (ccd)		(ccs)
	Ξ_{cc}^{++}	Ξ_{cc}^{+}	Ω_{cc}^{+}
M_1 (GeV)	3.70		3.80
M_o (GeV)	3.63		3.72

J.M. Richard[21a] estimated also the jerarchy of the lifetimes, extrapolated the analysis of Guberina, Ruckl and Trampetic[20a] and predicted:

$$\tau(\Xi_{cc}^{+}) < \tau(\Omega_{cc}^{+}) < \tau(\Xi_{cc}^{++}).$$

5. The future experiments

After this review of only some of the problems to be faced in the near future, we may recall very briefly the expectations of the future fixed target experiments.

WA89 has collected a total of over 600 million triggers with a very good experimental setup. Since it uses a Σ^- beam, a very large number of charmed baryons is expected. In preliminary analyses (on about 180 million triggers) WA89 provided[22] evidence for the decay modes $\Xi_c^+ \rightarrow \Lambda^o K^- 2\pi^+$ and $\Xi^- 2\pi^+$; the first evidence for the decay $\Xi_c^o \rightarrow \Lambda^+ K^- \pi^+$ and as many as

seven different decay modes of the Ω^+_c baryon. Thus, the baryon sector is expected to provide very good experimental measurements in the near future.

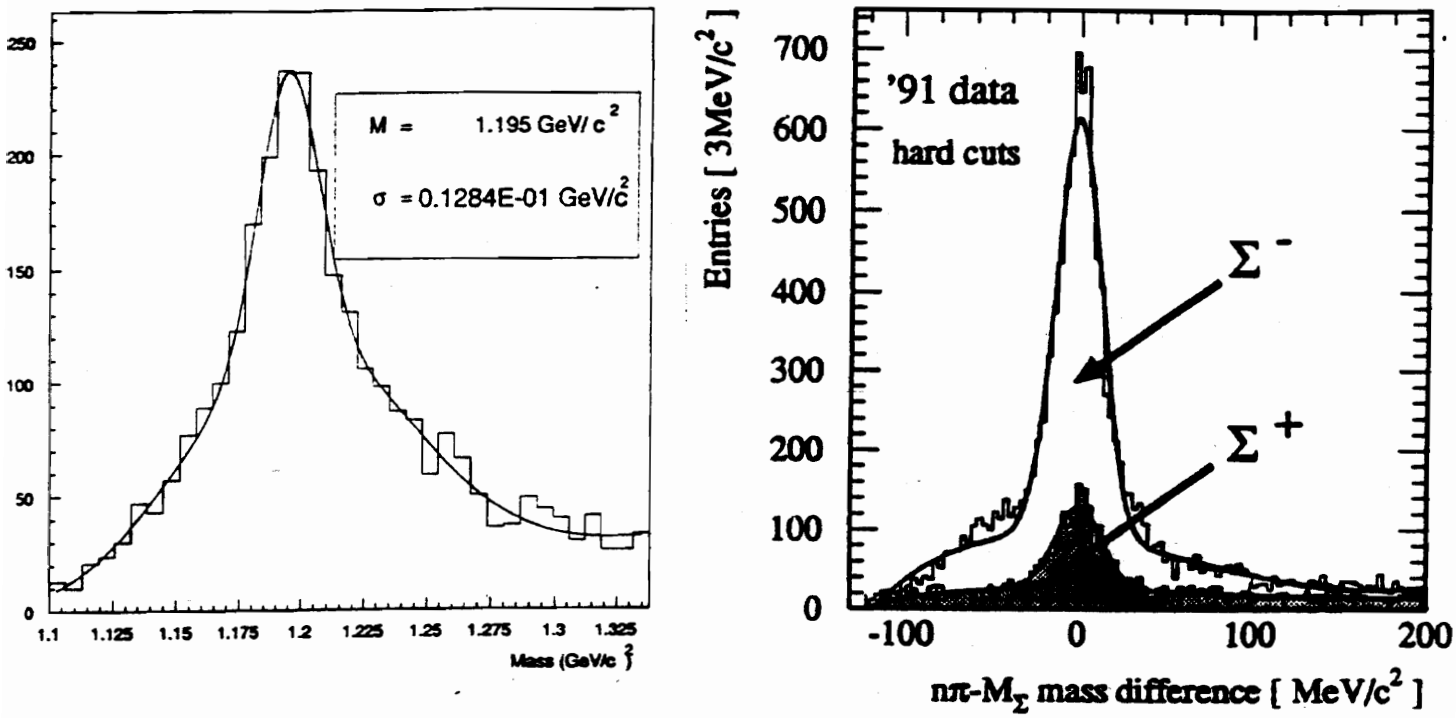

Fig. 9 Mass of the Σ hyperon measured detecting the neutron with an hadron calorimeter.
a) E687: artificial neural network, sample calorimeter; b) WA89: SPACAL fiber calorimeter.

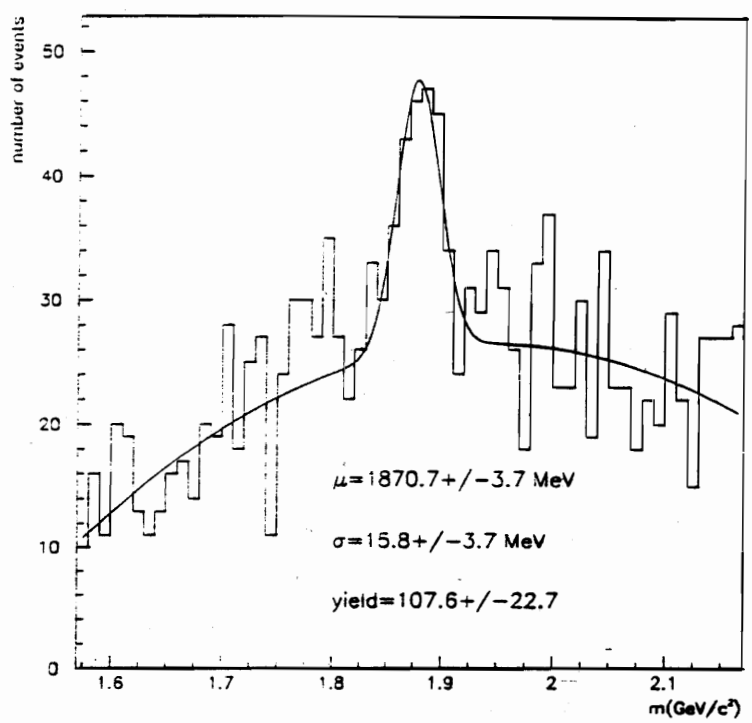

Fig. 10 $M(K^o_1\pi^+\pi^+\pi^-)$ for the decay $D^+\rightarrow K^o_1\pi^+\pi^+\pi^-$ with the K^o_1 measured by the hadron calorimeter (E687 data).

E781 is expecting to collect about 100,000 fully reconstructed $\Lambda^+_c\rightarrow pK^-\pi^+$ decays; over 50,000 $\Xi_c^+\rightarrow\Lambda^oK^-2\pi^+$, $\Xi_c^o\rightarrow\Lambda^oK^-\pi^+$, $\Omega_c^+\rightarrow\Xi^-K^-2\pi^+$. E831, on the other hand is expecting to collect over 20,000 fully reconstructed $\Lambda^+_c\rightarrow pK^-\pi^+$ decays.

The competition will be played on the field of the improvements in detector performances. For instance, E687 has developped an artificial neural network[23a] to extract informaion on the direction of neutral hadrons from the data recorded by the E687 hadron calorimeter. Fig.s 9 compare the reconstructed mass of the Σ particles by using the neutron direction determined in the 3-sector hadron calorimeter[23a] (fig. 9a) to the reconstructed mass of the beam particles of WA89[24] using the SPACAL fiber calorimeter (fig. 9b). The two resolutions are σ=12 MeV for E687 and 40 MeV (estimated) for WA98. E687, by reconstructing "kink candidates", is unable to determine whether the decaying particle is a sigma or an anti-sigma, while WA89 knows a priory the mass of the sigma hyperon. Fig. 10 shows finally the mass distribution obtained by E687[23b], of the decay $D^+ \rightarrow K^0_l\, \pi^+\pi^+\pi^-$. The resolution is about 14 MeV and proves the role that the performance of the different components of the detectors will play in the future experiments. The neutron channels should account for about 50% of the total decay of the Λ^+_c baryon. There are no doubts that the detection of the neutral decay channels will be a crucial target of charm physics in the near future.

5. Conclusions

In conclusion, the future of charm physics looks more than interesting and full of expectations. There is a very rich hunting territory and a healthy competition among experiments using colliding beams, or different beams on fixed targets. The baryon lifetimes to measure; the discovery of very many possible decay modes of both mesons and baryons; the several absolute branching fractions to set; the semileptonic multiplicity saturation to clarify; the fully leptonic modes to discover; all the spectroscopy of both hidden and open charm particles (both mesons and baryons) to complete; a wealth of rare processes within or outside of the Standard Model to discover (or to set upper limits for); the territory of radiative decays to explore. All this is quite a respectable program to fullfill for the next decade, not to mention the improvement of the (mostly systematic) uncertainty for the quantities already known. The very final conclusion could be summarized by fig. 11 which needs no caption.

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Fig. 11

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